Galileo Galilei

Introduction

Galileo Galilei (1564–1642) was one of the most significant figures of the Scientific Revolution. Galileo was involved in nearly all fields of natural philosophy, including astronomy, mathematics, and what we now term "physics." He is rightly considered one of the founders of modern physics and astronomy, and one of the main originators of the modern scientific method. Galileo's study of motion became the foundation for Newton's laws of motion and the principles of inertia and gravity. His astronomical studies were instrumental in supporting the heliocentric model of the solar system first propounded by Copernicus. He should also be credited with making experimentation the basis of scientific study, and with the use of mathematics as the fundamental means for expressing and validating the findings of experimental investigation. Galileo's application of mathematics to experimental results has become one of the most important aspects of modern science.

Galileo made important improvements to the telescope, which enabled him to make great advances in astronomical observation. His observations emboldened him to become the most important advocate of Copernicanism—the astronomical system created by Nicolaus Copernicus (1473–1543)—and his support ultimately ushered in the Copernican revolution in astronomy.

Copernicus had devised a heliocentric model in which he posited that the Earth revolved around the sun (in perfect circles). Contrary to the Ptolemaic system and Christian cosmology, Copernicus positioned the sun as a fixed center around which Mercury, Venus, Earth, Mars, Jupiter, and Saturn orbited. Furthermore, Copernicus posited the diurnal rotation of the Earth on its own axis in addition to its annual revolutions around the sun.

The Copernican system was at odds with the current Christian cosmology of a geocentric universe. Yet it was mostly considered a hypothetical computing scheme, a mere intellectual exercise—that is, until Galileo trumpeted Copernicanism and supported it with experimental evidence. With Galileo's observations and declarations, the heliocentric model gained ascendancy. Only by refusing to look through the telescope or suggesting that the telescope had produced illusions could scholars deny the explanatory efficacy of heliocentrism (some actually took this tack and refuted Galileo's conclusions).

Galileo's assertion and defense of Copernican heliocentrism brought him under suspicion and eventually aroused the opposition of the Catholic Church and the Roman Inquisition. His *Dialogue Concerning the Two Chief World Systems* (1632) was placed on the Index of Forbidden Books in 1633. It remained proscribed well into the nineteenth century. Galileo was forced to recant his heliocentric views and was placed on house arrest for the rest of his life, although his ideas circulated widely among natural philosophers.

Galileo's Personal Background

Galileo was born in Pisa, Tuscany, the oldest of six children. He came from a noble family, but his father had very little money. His father convinced him to attend the University of Pisa, after discouraging him from pursuing the priesthood. Because it did not yield enough income, his father intentionally steered him away from specializing in mathematics, and when Galileo first started college he was working toward a medical degree, per his father's urging. However, after happening upon a geometry lecture, Galileo decided to pursue mathematics and natural philosophy rather than medicine.

During his time at the University of Pisa, Galileo also took an interest in the study of fine art. He even taught courses on the techniques of perspective and chiaroscuro at the Accademia delle Arti del Disegno in Florence. However, as a result of his family's economic hardships, Galileo was forced to leave the University of Pisa before completing his degree. In 1589, based on his writings on motion, Galileo was offered a professorship and was appointed the chair of mathematics at the University of Pisa. By 1592, Galileo had moved to Padua, where he became a professor of mathematics and astronomy at the university. He remained at Padua for eighteen years.

Galileo's Scientific Contributions

Over the course of his career Galileo made many significant scientific discoveries and contributions in the areas of astronomy, motion, and applied mathematics. Galileo also contributed several innovations to the field of applied science, including improvements to the telescope, enhancements to the compass, and the invention of the thermoscope, a precursor of the modern thermometer.

Galileo's studies in motion led to a significant breakthrough and the overthrow the Aristotelian system of motion. Opposing the *a priori* assumptions of Aristotelian metaphysics, which held that bodies had inherent properties that impelled them to move to their natural resting places, Galileo introduced the empirical study of motion.

He also inverted the earlier process of treating mathematics in connection with nature. Rather than trying to reconcile nature with mathematic principles posited in advance, Galileo conducted experiments and applied measurement and mathematics to his experimental observations. That is, he began with the observed motion of bodies and derived the mathematical principles of motion from his observations. Using this methodology, which accords with the modern scientific method, Galileo unveiled two major principles of motion: the principle of uniform acceleration (the principle that bodies of whatever weight fall at the same rate, and not at a rate proportional to their weight, as had been held) and the principle of uniformly accelerated motion (the principle that falling bodies increase in speed uniformly with time and distance).

Galileo also introduced the notion of the vector to the study of projectiles and found that projectiles move in a parabolic motion. This finding had a military application. The parabolic motion of projectiles was used to determine the best angle at which to fire projectiles from a gun (for ultimate distance), which was found to be when the gun barrel was at a 45-degree angle of inclination from the horizon.

Using his enhanced version of Lippershey's telescope, Galileo was able to make many astronomical discoveries, including the confirmation of the phases of Venus, the discovery of the four largest satellites of Jupiter (named the Galilean moons in his honor), and the discovery, observation, and analysis of sunspots. He published some of these findings in a book entitled *Sidereus Nuncius*, or *Starry Messenger* (1610).

Johannes Kepler wrote a foreword to *Starry Messenger*, praising Galileo and his groundbreaking advances in astronomy. This commendation sparked the interest of the Grand Duke of Tuscany, Cosimo II de' Medici, who appointed Galileo as his court mathematician.

Following *Starry Messenger*, Galileo discovered the phases of Venus, which resulted in a description of periodic phasing due to Venus orbiting the sun. This corroborated Copernicus's heliocentric model. Galileo also provided some of the first observations and analyses of sunspots. The very concept of sunspots challenged Aristotle's classification of the sun as a flawless body or object. Several European astronomers, including German Professor Christoph Scheiner, disputed Galileo's theory of the phases of Venus, as well as his ideas about sunspots. For the first time, in a response letter to Scheiner in 1613, Galileo openly supported his belief in Copernicus's heliocentric system.

Galileo and the Catholic Church

Throughout his career, Galileo's support and advocacy of Copernicus's heliocentric model met with strong opposition from many astronomers and high members of the Catholic Church. The standard and accepted worldview at the time was a combination of the Tychonic system, developed by astronomer Tycho Brahe, and the Ptolemaic system, which argued that the earth was the center of the universe around which all other objects revolved (i.e., geocentrism).

Between 1613 and 1615, a letter that Galileo had written to a friend supporting the Copernican heliocentric model circulated widely throughout powerful civic and religious circles. Galileo personally sent a copy to the esteemed Cardinal Robert Bellarmine, who strongly opposed Copernicanism. The theories espoused by the heliocentric system posed a threat to the accepted Christian cosmology. The Roman Inquisition investigated the validity of Copernicus's heliocentric model in 1615. The Inquisition echoed the verdict at which Cardinal Bellarmine had arrived, which was that heliocentrism was only to be interpreted as a hypothesis, and should not be understood as accepted truth. Bellarmine had personally suggested this to Galileo, and advised that he continue to treat it as such until explicit evidence of its validity demonstrated otherwise. The Roman Inquisition consigned Copernicus's *On the Revolutions of the Heavenly Spheres* (1543) to the Index of Forbidden Books in 1616, pending corrections.

Despite his doctrinal and personal deviations from Church teaching, Galileo was a devout Catholic, and even sent two of his (illegitimate) daughters to the convent. He enjoyed friendships with several clergymen, most importantly Cardinal Maffeo Barberini, who in 1623 became Pope Urban VIII. Barberini and others in the church encouraged Galileo to avoid publicly supporting heliocentrism. For the next several years, Galileo continued to accept Copernicus's heliocentric model as scientific truth, but he heeded the advice of his friends and did so privately. Four years after the Inquisition's investigation into Copernicanism, Galileo and a Jesuit priest, Orazio Grassi, had a running disagreement over the motion of comets. This allowed Galileo to indirectly defend the heliocentric model without explicitly referencing Copernicus.

After Pope Urban VIII's election in 1623, Galileo published a contentious and argumentative treatise that he had written in response to Grassi's writings on comets. *Il Saggiatore* (*The Assayer*) argued against contemporary and ancient teachings of astronomical theory and asserted new scientific hypotheses.

In *The Assayer*, Galileo advanced the position that quantification was the only means of understanding natural phenomena. Galileo's treatise posed a major challenge to Aristotelian theory, including Aristotle's emphasis on the qualitative aspects of objects. Part of Aristotle's theory of objects involved the distinction between matter and form. Matter made up the physical properties of an object or item, such as wood or metal. "Form" referred to its qualitative essence or purposeful design. Galileo viewed Aristotle's understanding of form to be teleological (tending toward an ultimate disposition or destination) so he dispensed with the concept of form altogether. This allowed Galileo to consider the behavior of objects in terms of principles that applied to all objects equally. Objects were seen as obeying principles of motion and matter rather than their own intrinsic dispositions. In other words, by dispensing with Aristotelian form, Galileo was able to advance the modern notion of natural causality into the study of motion. The result was the final overthrow of the Aristotelian system.

Galileo and the Dialogue

A few years after publishing *The Assayer*, Galileo started work on what would become his most controversial writing: *Dialogo Sopra i Due Massimi Sistemi del Mondo,* or *Dialogue Concerning the Two Chief World Systems* (1632). This comprised a culmination and summary of Galileo's scientific views and offered an explicit comparison between Copernicus's heliocentric model and Ptolemy's geocentric system. In the *Dialogue*, Galileo aimed at exonerating the Copernican heliocentric model.

The book covered Galileo's observations on many major scientific issues of his day, in addition to astronomy. Parts of the work were meant to highlight what Galileo considered to be valuable advancements in natural philosophy, including William Gilbert's findings on magnetism. Another section of the book, in which Galileo was particularly invested, concerned the motion of the Earth. Galileo believed that Earth's motion could be discovered and explained through an investigation of oceanic tides. Ultimately, however, his findings on tides and their correlation to the motion of the earth were deemed to be mistaken.

Galileo completed the *Dialogue* in 1630 and was given permission by the Inquisition to publish it two years later, in 1632. This was largely due to Galileo's well-known relationship with Pope Urban VIII.

Through the use of a narrative structure in the book, Galileo hoped to dodge the Inquisition's ban on Copernicus's heliocentrism. The *Dialogue* was constructed as a discussion between three different men over the course of four days. Two of the men were philosophers, and the other was a layman. The layman, Sagredo, was a mediator who entered into the discussion with the two philosophers. The first philosopher, Salviati (named after one of Galileo's friends), was an advocate of Copernicus and the heliocentric model. Salviati espoused several of Galileo's theories in the book. The second philosopher, Simplicio (a name that suggested naïve simplicity), described the tenets of geocentrism and was depicted as a staunch proponent of Aristotle and Ptolemy. Galileo used this discussion as an opportunity to demonstrate what he viewed as the major weaknesses of the Aristotelian and Ptolemaic systems.

After the publication of the *Dialogue*, Pope Urban VIII became convinced that the character Simplicio was based on him. As a result of this perceived insult, Pope Urban VIII banned publication of the *Dialogue* and demanded that the Inquisition investigate Galileo. A year after the publication of the *Dialogue*, the Roman Inquisition sent for Galileo and put him and his work on trial for breaking the ban on promoting Copernicanism. He was charged with heresy, and ultimately disavowed his belief in heliocentrism to avoid torture by the Inquisition. As a result, the Inquisition condemned Galileo and placed the *Dialogue* on its Index of Forbidden Books. Due to Galileo's abjuration of Copernicanism, his sentence was limited to lifetime house arrest. After being sentenced to house arrest, Galileo spent the remaining years of his life in his villa in Arcetri, near Florence, where he continued to write about his scientific findings until his death in 1642. *Two New Sciences* detailed his work as a younger man on kinematics (a branch of classical mechanics that deals with the motion of objects) and the strength of materials. He never again publicly defended Copernicanism.

Over one hundred years later, in 1758, the Catholic Church eventually lifted its ban on Copernicanism and the heliocentric model. Galileo's *Dialogue* was not removed from the Index of Forbidden Books until 1835. It was not until 1992 that Pope John Paul II posthumously exonerated Galileo and reversed his sentence.

Summary:

- The Italian scientist Galileo Galilei was one of the most significant and influential figures of the Scientific Revolution.
- Galileo introduced empirical observation to the study of moving bodies, which led to the overthrow of the Aristotelian system and the introduction of modern causality to the study of motion.
- Given his transformative improvements to the telescope, Galileo made substantial discoveries and contributions to the field of astronomy.
- Until his condemnation by the Church, Galileo was a strong supporter of Copernicus and the heliocentric model.
- Galileo's publications in support of heliocentrism led to his condemnation by the Roman Inquisition and the banning of his writings by the Catholic Church.
- The ban on Copernicanism lasted until the mid-eighteenth century, and Galileo's *Dialogue* was not removed from the Index of Forbidden Books until 1835.